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DOMESTIC PREPAREDNESS PROGRAM TESTING OF SAW MINICAD MKII DETECTOR AGAINST CHEMICAL WARFARE AGENTS SUMMARY REPORT

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This report characterizes the chemical warfare (CW) agent detection potential of the commercially available surface acoustic wave (SAW) MiniCAD mkII. The instrument was tested against mustard (HD), sarin (GB), and tabun (GA), vapor at various conditions. This report is intended to provide the emergency responders concerned with CW agent detection an overview of the detection capabilities of the SAW MiniCAD mkII.

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PREFACE

The work described in this report was authorized under the Expert Assistance (Equipment Test) Program for the U.S. Army Soldier and Biological Chemical Command (SBCCOM) Program Director for Domestic Preparedness. This work was started in September 1999 and completed in August 2000.

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SUMMARY REPORT

1. INTRODUCTION

The Department of Defense (DOD) formed the Domestic Preparedness (DP) Program in 1996 in response to Public Law 104-201. One of the objectives is to enhance federal, state, and local capabilities to respond to Nuclear, Biological, and Chemical (NBC) terrorism incidents. Emergency responders who encounter either a contaminated or potentially contaminated area must survey the area for the presence of either toxic or explosive vapors. Presently, the vapor detectors commonly used are not designed to detect and identify chemical warfare (CW) agents. Little data are available concerning the ability of these commonly used and commercially available detection devices to detect CW agents. Under the DP Expert Assistance (Test Equipment) Program, the U.S. Army Soldier and Biological Chemical Command (SBCCOM) established a program to address this need. The Applied Chemistry Team (ACT), formerly known as the Design Evaluation Laboratory (DEL), Aberdeen Proving Ground, MD, performed the detector testing. ACT is tasked with providing the necessary information to aid authorities in the selection of detection equipment applicable to their needs.

Reports of the instrument evaluations are posted in the Homeland Defense website (http://www2.sbccom.army.mil/hld/downloads/index.htm) for public access. Instruments evaluated and reported in 1998 and in 1999 include:

- MiniRAE plus from RAE Systems, Incorporated
- Passport II Organic Vapor Monitor from Mine Safety Appliances Company
- PI-101 Trace Gas Analyzer from HNU Systems, Incorporated
- TVA 1000B Toxic Vapor Analyzer (PID and FID) from Foxboro Company
- Draeger Colorimetric Tubes (Thioether and Phosphoric Acid Ester) from Draeger Corporation
- Photovac MicroFID Detector from Perkin-Elmer Corporation
- MIRAN SapphIRe Air Analyzer from Foxboro Company
- MSA Colorimetric Tubes (HD and Phosphoric Acid Ester) from Mine Safety Appliances, Company
- M90-D1-C Chemical Warfare Detector from Environics OY, Finland
- APD2000 Detector from Environmental Technologies Group, Incorporated

More recently (2000), the evaluation of instruments continued to include the surface acoustic wave (SAW) MiniCAD mkII (Microsensor Systems, Incorporated, Bowling Green, KY), UC AP2C Monitor (Proengin, Incorporated, France), the ppbRAE Photo-Ionization Detector (RAE Systems, Incorporated, Sunnyvale, CA), the SABRE 2000 (Barringer

Technologies, Incorporated, Warren, NJ), and the CAM (Type L) (Graseby Dynamics Ltd, Herts, UK). Each of these evaluations will be reported separately. This report pertains to the evaluation of the SAW MiniCAD mkII from Microsensor Systems, Incorporated.

2. OBJECTIVE

The objective of this report is to assess the capability and general characteristics of the SAW MiniCAD mkII (SAW chemical agent detector) to detect CW agent vapors. The intent is to provide the emergency responders concerned with CW agent detection an overview of the detection capabilities of the instrument.

3. SCOPE

The scope of this evaluation is to characterize the CW agent vapor detection capability of this SAW detector based instrument. Due to time and resources limitations, the agents used were limited to tabun (GA), sarin (GB), and mustard (HD). These representative CW agents are believed to be the most likely threats. Test procedures followed those described in the Phase 1 Test Report.[1] The test concept was as follows:

- Determine the minimum detectable level (MDL) where repeatable detection readings are achieved for each selected CW agent. The current military Joint Services Operational Requirement (JSOR)[2] served as a guide for detection sensitivity objectives.

- Investigate the humidity and temperature effects on detection response.

- Observe the effects of potential interfering vapors upon detection performance in the laboratory and in the field.

4. EQUIPMENT AND TEST PROCEDURES

4.1 Detector Description.

Microsensor Systems, Incorporated, a SAWTEK Company (Bowling Green, KY), is the manufacturer of the SAW MiniCAD mkII. Instrument description and operating procedures originate from the User's Guide.[3] The SAW device employs a pair of micro sensors that respond to changes in the mass of the surface coatings resulting in vibration frequency changes when a vapor sample flows over them in a compact, lightweight chemical agent detector (CAD). The pocketsize instrument detects nerve and blister agents simultaneously. The instrument will produce an alarm (visibly and audibly) when the preset threshold levels for the CW agent detection algorithm are matched. The instrument differentiates between blister and nerve agents detection by corresponding H or G alarm.

A digital photograph of the SAW MiniCAD mkII detector is shown in the following Figure. Three units were purchased for this evaluation and randomly labeled A, B, calculated HD volatility of 92 mg/m3 at 0°C easily produces a vapor concentration higher than the 2 mg/m^3 JSOR detection criteria allowing the instrument to be evaluated at 0°C.

4.4 Agent Vapor Quantification.

The generated agent vapor concentrations were analyzed independently and reported in milligrams per cubic meter (mg/m^3) and parts-per-million (ppm) units in the data tables. The vapor concentration was quantified by utilizing the manual sample collection methodology[5] using the Miniature Continuous Air Monitoring System (MINICAMS®) (O. I. Analytical, Incorporated, Birmingham, AL). The MINICAMS® is equipped with a flame photometric detector (FPD), and was operated in phosphorus mode for the GA and GB agents, and sulfur mode for HD.

This system normally monitors air by collection through sample lines and subsequently adsorbing the CW agent onto the solid sorbent contained in a glass tube referred to as the pre-concentrator tube (PCT). The PCT is located after the MINICAMS® inlet, and then the concentrated sample is periodically heat desorbed into a gas chromatographic capillary column for subsequent separation, identification, and quantification. For manual sample collection, the PCT was removed from the MINICAMS® during its sampling cycle and connected to a measured suction source to draw the vapor sample from the agent generator. The PCT was then re-inserted into the MINICAMS® for analysis. This "manual sample collection" methodology eliminates potential loss of sample along the sampling lines and the inlet assembly when the MINICAMS® is used as an analytical instrument. The calibration of the MINICAMS® was performed daily using the appropriate standards for the agent of interest. The measured mass equivalent (derived from the MINICAMS® chromatogram) divided by the total volume (flow rate × time) of the vapor sample drawn through the PCT produces the sample concentration that converts into milligrams/cubic meter.

4.5 Field Interference Tests.

The instruments were tested outdoors in the presence of common potential interferents such as the vapors from gasoline, diesel fuel, jet propulsion fuel (JP8), kerosene, Aqueous Film Forming Foam (AFFF, used for fire fighting), household chlorine bleach, and insect repellent. Vapor from a chlorinating decontaminant for CW agents [10% calcium hypochlorite (HTH) slurry], engine exhausts, burning fuels, and other burning materials were also tested. The objective was to assess the ability of the instruments to withstand outdoor environments and to resist false alarming indications when exposed to the selected substances. In these tests, no CW agent was present.

The field tests were conducted outdoors at M-Field, Edgewood Area, Aberdeen Proving Ground, in August 2000. These experiments involved open containers, truck engines, and fires producing smoke plumes, which were sampled by the detectors at various distances downwind. The SAW MiniCAD units were carried to the smoke or fume test plume to achieve moderate but not exaggerated exposures (e.g., 0.5-2 m for vapor fumes and 2-5 m for smokes).

Confidence checks were performed on each instrument at the beginning of each testing day and periodically between tests. The two units were exposed to each interferent for 5 min for three trials when possible. Testing continued with the next challenge after the instruments were thoroughly recovered from prior exposure.

4.6 Laboratory Interference Tests.

The laboratory interference tests were designed to assess the effect on the detectors of vapor exposure from potential interfering substances. The substances were chosen based on the likelihood of their presence during an emergency response by first responders. Additionally, the laboratory interference tests were conducted to assess the CW agent detection capability in the presence of the selected vapor generated from diesel fuel or fire fighting AFFF liquid.

The units were tested against 1% of the headspace concentrations of vapors of gasoline, JP8, diesel fuel, household chlorine bleach, floor wax, AFFF, Spray 9 cleaner, Windex®, toluene, and vinegar. They were also tested against 25 ppm ammonia (NH_3). If the detector false alarmed at 1% concentration, it was tested at the 0.1% concentration of the substance. A dry air stream carries the headspace vapor of the substance by sweeping it over the liquid in a tube or through the liquid in a bubbler to prepare the interferent gas mixture. Thirty milliliters/minute or 3 mL/min of this vapor saturated air was then diluted to 3 L/min with the conditioned air at 23 °C and 50% RH to produce the 1 or 0.1% concentration of interferent test mixture, respectively. The 25-ppm NH_3 was derived by proper dilution of a stream from an analyzed 1% NH_3 vapor (10,000 ppm) compressed gas cylinder with the appropriate amount of the conditioned air.

For the tests that included CW agent, the interferent test gas mixture was prepared similarly. The resultant stream of 3 L/min of CW agent vapor was used as a dilution stream to blend in with the 3 or 30 mL/min of the substance vapor to obtain the desired 0.1 or 1% mixture of the substance vapor in the presence of CW agent concentration. The two units were tested three times with each agent/interferent combination.

5. RESULTS AND DISCUSSION

5.1 Minimum Detectable Levels.

The minimum detectable levels (MDLs) for the SAW MiniCAD are shown in Table 1 for each agent at ambient temperatures and <5% RH. The MDL values represent the lowest CW agent concentration that produced an alarm consistently for two of the SAW MiniCAD units. Table 1 shows the range of response times observed for the MDL listed. The MDL concentrations are expressed in milligrams/cubic meter with equivalent parts-per-million values given in parentheses. To compare the detectors' performance, the current military JSOR requirements for CW agent sensitivity for point detection alarms, the Army's established values for immediate danger to life or health (IDLH), and the airborne exposure limit (AEL) are also listed in Table 1. Army Regulation (AR) 385-61 is the source for the IDLH and AEL values for GA and GB, and the AEL value for HD. The AR 385-61 does not establish an IDLH for HD due to concerns over carcinogenicity.

No MDL could be established for the SAW detectors in a 60 sec response time as stated by the manufacturer. Given that none of the units responded within 60 sec during the CW evaluations and because of the inability for the operator to determine the beginning and the end of a cycle for the SAW units, extra long exposure time was tried for observation purposes to determine if there were additive effects. Observations showed these detectors to require longer response times due to the sampling (40 sec) and desorption (20 sec) cycles that may have prevented detection within the 60 sec the manufacturer claim. Alarm responses usually required more than one 60-sec cycle even at the higher concentrations. For example, if the agent challenge was introduced at other than the beginning of the sampling cycle, it would have prevented a full sample analysis for that cycle. This prevented the response time from occurring within 1 min unless the concentration was sufficiently high such that a partial sample would cause an alarm signal. Many times throughout the evaluations, the detectors produced no alarm at concentrations greater than the JSOR levels even with exposure times up to 10 min.

None of the SAW units could detect at the JSOR, IDLH, or AEL levels for GA, GB, or HD in <2 min or even up to 5 min. The units were able to detect HD at approximately the JSOR concentration level with 7 min response times.

Table 1. Minimum Detectable Level (MDL) for SAW MiniCAD mkII at Ambient Temperature and 5% RH

AGENT	Concentration in Milligrams per Cubic Meter (mg/m^3) With Parts per Million (ppm) Values In Parenthesis and Response Times			
	SAW MDL	JSOR*	IDLH**	AEL***
HD	2.3 (0.35) in 235-444 sec	2.0 (0.300) in 120 sec	N/A	0.003 (0.0005) up to 8 hr
GA	5.0 (0.74) in 121-304 sec	0.1 (0.015) in 30 sec	0.2 (0.03) up to 30 min	0.0001 (0.000015) up to 8 hr
GB	0.4 (0.07) in 158-301 sec	0.1 (0.017) in 30 sec	0.2 (0.03) up to 30 min	0.0001 (0.000017) up to 8 hr

* Joint Service Operational Requirement for detectors.
** Immediate Danger to Life or Health values from AR 385-61 to determine level of CW protection.
Personnel must wear full ensemble with SCBA for operations or full-face piece respirator for escape.
***Airborne exposure limit values from AR 385-61 to determine masking requirements.
Personnel can operate for up to 8 hr unmasked.

5.2 Temperature And Humidity Effects.

Tables 2, 3, and 4 list the responses of the SAW detectors at the various test conditions for HD, GA, and GB, respectively. The results show the alarm reading and the range of response times for the three SAW units tested. The results listed represent multiple challenges with test units at agent concentrations between 0.4 and 43 mg/m^3. These units demonstrated agent detection with more consistent responses when exposed to relatively high concentrations of CW agent vapors for several minutes.

At times, Unit B developed symptoms of contamination that caused long recovery times. When this became a problem, Unit C was tested in its place. Likewise, when any given unit was experiencing problems, the two best working units would be tested on that day. Therefore, the results listed in the tables contained many "not tested" situations.

High temperature (40 °C) seemed to affect the instrument's detection capability. The units would not alarm to HD up to 9 mg/m^3 or to GA up to 4.5 mg/m^3 at 40 °C. High temperature appears to have defeated the proper functioning of the sample concentrator. The units alarmed to GB only at a relatively high concentration of 3.8 mg/m^3.

Units A and B appeared to be most problematic with GA detection at all conditions. Responses to GA vapor were erratic. No consistent data could be gathered for GA among the units tested although Unit C was able to detect GA at concentrations >2.7 mg/m^3. In general, humidity changes did not appear to cause adverse effects on these SAW detectors except that Unit A had problems at 90% RH for both GA and GB.

Recovery times typically required several cycles (several minutes) after agent exposure. The recovery time required up to 25 min for the units to clear when operated in cold temperatures. The units were observed to require longer recovery times even after the routine confidence checks as the testing progressed.

Table 2. SAW MiniCAD mkII Responses to HD Vapor Concentrations

Temp., °C	Relative Humidity, %RH	HD Challenge Concentration		Unit A		Unit B		Unit C	
		mg/m³	ppm	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min
0	0	3.4	0.48	H Low	7-8	H Low	3-5	H Low	4-6
40	<5	Up to 9	1.45	No alarm	No alarm	No alarm	No alarm	No alarm	No alarm
20	<5	2.0	0.30	H Low	6-7	No alarm	No alarm	Not tested	Not tested
		2.3	0.35	H Low	4-6	H Low	6-7	Not tested	Not tested
		3.0	0.45	H Low	2-4	H Low	4-5	Not tested	Not tested
		3.4	0.51	H Low	3-4	H Low	3-4	Not tested	Not tested
20	>90	3.7	0.56	H Low	3-4	H Low	5-6	Not tested	Not tested
20	50	4.3	0.65	H Low	2-3	H Low	3-4	Not tested	Not tested
20	<5	8.1	1.20	H Low	1.5-2	H Low	2-3	Not tested	Not tested
		23	3.50	H Low	1.5-2	H Low	1-2.5	Not tested	Not tested
		29	4.40	H Low*	~2	H Low	~2	Not tested	Not tested
		43	6.50	H Low*	~1	H Low	~1.5	Not tested	Not tested

*Low alarm changed to high alarm during clear down cycles

Table 3. SAW MiniCAD mkII Responses to GA Vapor Concentrations

Temp. °C	Relative Humidity, %RH	GA Challenge Concentration		Unit A		Unit B		Unit C	
		mg/m³	ppm	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min
5	0	Up to 4.5	0.63	Not tested	Not tested	No Alarm	No Alarm	No Alarm	No Alarm
40	0	Up to 4.5	0.63	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm	No Alarm
24	<5	2.7	0.41	No Alarm	No Alarm	Not tested	Not tested	G Low	4-4.5
22		4.0	0.60	No Alarm	No Alarm	Not tested	Not tested	G Low	3-3.5
20		5.0	0.74	G Low	~7	G Low	~2	G Low	2.5-5
23	50	5.2	0.77	No Alarm**	No Alarm	Not tested	Not tested	G Low	4.5-5.5
24	90	6.1	0.92	No Alarm	No Alarm	Not tested	No Alarm	G High	3.5-4
24	<5	7.0	1.10	No Alarm	No Alarm	Not tested	No Alarm	G Low*	2-3

* Low alarm changed to high alarm during clear down cycles
**Alarmed 2 out of 3

Table 4. SAW MiniCAD mkII Responses to GB Vapor Concentrations

Temp. °C	Relative Humidity, %RH	GB Challenge Concentration		Unit A		Unit B		Unit C	
		mg/m³	ppm	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min	Alarm Reading	Response Time Range, min
5	<25	1.0	0.16	No Alarm	No Alarm	G Low	3-4	G Low	3.5-4.5
		1.7	0.28	G Low	~3	G Low	1.5-2	Not tested	Not tested
40	<5	1.9	0.35	No Alarm	No Alarm	No Alarm	No Alarm	Not tested	Not tested
		3.8	0.70	G Low**	3-3.5	G Low**	2.5-4.5	Not tested	Not tested
20-22	<5	0.40	0.07	G Low	4-5	G Low	2.5-4.5	Not tested	Not tested
		0.6	0.10	No Alarm	No Alarm	Not tested	No Alarm	No Alarm	No Alarm
		1.0	0.20	G Low	1.5-2.5	G Low	1.5-2.5	Not tested	Not tested
		1.9	0.33	G Low	2-3	Not tested	Not tested	G Low	1.5-2
		9.7	1.70	G Low	1-1.5	Not tested	Not tested	G Low	1-1.5
		36	6.20	G High	1-2	Not tested	Not tested	G High	1-1.5
22	50	2.1	0.36	G Low	1.5-2	Not tested	Not tested	G Low	1.5-2
22	90	2.0	0.35	No Alarm***	3.5	Not tested	Not tested	G Low	1.5-3

** Alarmed 2 out of 3
***Alarmed 1 out of 3 trials

5.3 Field Interference.

The results of the field test interferent exposures are presented in Table 5. The ambient temperature and relative humidity levels during these tests were in the range of 27-32 °C and 45-80% RH, with gentle wind. Units A and B were used for the field interference evaluations as Unit C would not power up into ready mode. Units A and B were slow to alarm to the simulant checks and required up to 10 min to clear after the simulant alarm. Neither unit responded to any of the field interferences tested. There were no false alarms. Each unit was tested 3 times for 5-min exposures against the listed interferences with the exception of the insect repellent, doused fire, and burning tire, as shown.

Post field test responses showed residual effects from the field exposures. Tests of the SAW MiniCAD Units A and B against HD required twice the response time to alarm to agent concentrations as required for similar concentrations prior to the field test. Unit A would not respond at all to GA or GB after field test exposures. Unit B was slower to alarm to GA than before the field test and needed more than 20 min to recover after an agent challenge. Unit B responded to GB equally well before and after the field test for exposures.

Table 5. SAW MiniCAD mkII Units A and B Field Interference Testing Summary

Interferent	Total Trials, 5 Min Exposures	Total False Alarms
Gasoline Exhaust, Idle	6	0
Gasoline Exhaust, Revved	6	0
Diesel Exhaust, Idle	6	0
Diesel Exhaust, Revved	6	0
Kerosene Vapor	6	0
Kerosene on Fire	6	0
JP8 Vapor	6	0
Burning JP8 Smoke	6	0
Burning Gasoline Smoke	6	0
Burning Diesel Smoke	6	0
AFFF Vapor	6	0
Insect Repellent	2	0
Diesel Vapor	6	0
Gasoline Vapor	6	0
HTH Vapor	6	0
Bleach Vapor	6	0
Burning Cardboard	6	0
Burning Cotton	6	0
Burning Wood Fire Smoke	6	0
Doused Wood Fire Smoke	2	0
Burning Rubber	4	0

5.4 Laboratory Interference Tests.

Table 6 presents the results of testing the detectors with conditioned air containing GB or HD in the presence of either diesel fuel vapor or AFFF vapor. The tests were completed at ambient temperatures and 50% RH using CW agent concentrations greater than the MDL. Each test was repeated three times. Units A and B were able to detect and identify the CW agent class in the presence of these vapors. Unit A did not alarm to GB even with an 8-min exposure time.

Table 6. SAW MiniCAD mkII Results of Laboratory Interference Tests with CW Agents

Agent	Interferent	Concentration		Units A and B		
		mg/m³	ppm	Alarm Response		Range of Response Times (sec)
GB	1% AFFF	1.5	0.02	G	Low	97-268
	1% Diesel	1.5	0.02	G	Low	116-133*
HD	1% AFFF	6.6	1.00	H	Low	209-276
	1% Diesel	5.4	0.08	H	Low	182-252

*Unit B only. Unit A did not respond to GB even after an 8 min GB exposure.

Laboratory evaluations to determine if other potential interferents would cause the detector to false alarm are summarized in Table 7. These tests did not include CW agent and were conducted at ambient temperatures and 50% RH. Since the SAW Unit B would not respond to the simulant check and Unit C would not power on, the laboratory interferent testing was completed using Unit A only. Unit A was exposed twice to each of the substance vapors for a minimum of 5 min/trial. Because these substances did not cause false alarms at the 1% (of saturation) level, they were not tested at the 0.1% level.

Table 7. SAW MiniCAD mkII Results of Laboratory Interference Tests without Agents

Interferent	Unit A 5 min Interferent Exposures
1% JP8	No Alarm
1% Vinegar	No Alarm
1% Gasoline (*)	No Alarm*
1% Windex®	No Alarm
1% Spray Nine	No Alarm
1% Floor Wax	No Alarm
1% Bleach	No Alarm
1% Toluene	No Alarm
25 ppm Ammonia	No Alarm
1% AFFF	No Alarm
1% Diesel	No Alarm

*Unit alarmed for H Low approximately 6 min after having been removed from the source.

6. CONCLUSIONS

Conclusions are based solely on the results observed during this testing. Aspects of the detectors, other than those described, were not investigated.

Civilian first responders and HAZMAT personnel use immediate danger to life or health (IDLH) values to determine levels of protection selection during consequence management of an incident. The surface acoustic wave (SAW) MiniCAD devices demonstrated chemical warfare (CW) agent vapor detection for mustard (HD), tabun (GA), and sarin (GB) only at high concentrations or over >5 min response times. The instruments were unable to detect CW agent at the Joint Services Operational Requirement (JSOR), IDLH, or the airborne exposure limit (AEL) values for HD, GA, or GB. In addition, no consistent or conclusive analysis could be drawn from the GA data collected.

Humidity changes did not appear to cause adverse effects on the SAW detectors with the exception that Unit A had problems at 90% RH for both GA and GB. However, high temperatures affected the instrument's ability to detect the agents, and cold temperatures affected the instrument's ability to recover from agent exposures. The units also required long recovery times, as they were only able to detect the presence of agent vapor when exposed to higher agent concentrations. As testing progressed, the units were observed to require longer recovery time even after the routine confidence checks.

The problematic behaviors observed throughout the evaluation limit the usefulness of the SAW MiniCAD as a viable warning device. These instruments showed unpredictable behavior among the units that plagued the evaluation even though the detector appears to be unaffected by the commonly found substances used in the field and laboratory interferent tests. There were no false alarms recorded, however, the units performed sluggishly in responding to their simulant checks, indicating a lack of sensitivity.

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